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T^{3}B: Test New Building Mechanical System Acceptance Testing Procedures

TECHNOLOGY TRANSFER TEST BED PROGRAM

Field Demonstration of the Acceptance Test Procedure for Air Supply and Distribution Systems

by
Dahtzen Chu
Mark R. Imel

Four U.S. Army Corps of Engineers (USACE) Districts, one Area Office (AO), and one Directorate of Engineering and Housing (DEH) evaluated an acceptance test procedure for air supply and distribution systems. The purpose of the procedure is to determine if air supply and distribution systems in new buildings were installed properly and are operating in an energy-efficient manner by measuring critical energy, flow, pressure, and temperature parameters. The procedure will help inspectors to accept or reject testing, adjusting, and balancing work performed by the Contractor. The objective of this test was to determine the validity of the acceptance test procedure for use by Corps inspection personnel.

Based on the participants' responses to this demonstration, the acceptance test procedure is relatively easy to use, accurate, and appropriate for evaluating the installation and operation of air supply and distribution systems in new and existing Army facilities.

It is recommended that the acceptance procedure be incorporated into the USACE PROSPECT Quality Verification: Mechanical I course. The procedure will also be announced in HQUSACE Engineering Improvement Recommendation System (EIRS) Bulletins and construction division newsletters.

It is recommended that this procedure be used in the field and revised and updated after periodic review to prevent it from becoming obsolete. It is also recommended that the checklist portions of the procedure be used to establish a regular maintenance schedule.

TECHNOLOGY TRANSFER TEST BED PROGRAM
FINDINGS AND RECOMMENDATIONS OF TEST/DEMONSTRATION

WORK UNIT NO./TITLE OF TEST: T^{3}B, "Test New Building Mechanical System Acceptance Testing Procedures"

PERFORMING LABORATORY: USACERL

PRODUCT/SYSTEM: Acceptance test procedure for air supply and distribution systems

PERFORMING TEST SITES: The following Districts: Mobile AL; New York, NY; Savannah, GA; and Tulsa, OK. The Phoenix, AZ, Area Office and the Fort Riley, KS, Directorate of Engineering and Housing; at the following sites: Fort Drum, NY; Fort Huachuca, AZ; Fort Jackson, SC; Fort McClellan, AL; Vance Air Force Base (AFB), OK; Maxwell AFB, AL; Bates Field, AL; and Fort Riley, KS.

DESCRIPTION/OBJECTIVE OF TEST/DEMONSTRATION:

Four U.S. Army Corps of Engineers (USACE) Districts, one Area Office (AO), and one Directorate of Engineering and Housing (DEH) evaluated an acceptance test procedure for air supply and distribution systems. The purpose of the procedure is to determine if air supply and distribution systems in new buildings were installed properly and are operating in an energy-efficient manner by measuring critical energy, flow, pressure, and temperature parameters. The procedure will help inspectors to accept or reject testing, adjusting, and balancing work performed by the Contractor. The objective of this test was to determine the validity of the acceptance test procedure for use by Corps inspection personnel.

RESULTS OF TEST/DEMONSTRATION:

The participants were supportive of the concept of acceptance testing. Based on their responses to this demonstration, the acceptance test procedure is relatively easy to use, accurate, and appropriate for evaluating the installation and operation of air supply and distribution systems in new and existing Army facilities. However, the participants are concerned about acquiring funding for sufficient staffing and instrumentation.

RECOMMENDATION FOR PRODUCT/SYSTEM:

It is recommended that this procedure be used in the field and revised and updated after periodic review to prevent it from becoming obsolete. It is also recommended that the checklist portions of the procedure be used to establish a regular maintenance schedule.

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Four U.S. Army Corps of Engineers (USACE) Districts, one Area Office (AO), and one Directorate of Engineering and Housing (DEH) evaluated an acceptance test procedure for air supply and distribution systems. The purpose of the procedure is to determine if air supply and distribution systems in new buildings were installed properly and are operating in an energy-efficient manner. The objective of this test was to determine the validity of the acceptance test procedure for use by Corps inspection personnel.

Based on the participants' responses to this demonstration, the acceptance test procedure is relatively easy to use, accurate, and appropriate for evaluating the installation and operation of air supply and distribution systems in new Army facilities.

It is recommended that this procedure be used in the field and revised and updated after periodic review to prevent it from becoming obsolete. It is also recommended that the checklist portions of the procedure be used to establish a regular maintenance schedule.

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FOREWORD

This work was performed for the Directorate of Engineering and Construction, Headquarters, U.S. Army Corps of Engineers (HQUSACE), as a project in the Technology Transfer Test Bed (T^3B) program under the Corps of Engineers National Energy Team (CENET). The Work Unit is "Test New Building Mechanical System Acceptance Testing Procedures." The research used in this test was performed under Project 4A162784AT45, "Energy and Energy Conservation"; Work Unit 013, "Acceptance Testing for Energy Efficient Buildings." Mr. D. Beranek, CEMP-EE, was the HQUSACE T^3B Technical Monitor.

The field tests were administered by the Energy Systems Division (ES), U.S. Army Construction Engineering Research Laboratory (USACERL). Dr. G. R. Williamson is Chief, ES. Four USACE Districts (Mobile, AL; Savannah, GA; Tulsa, OK; and New York, NY), one Area Office (Phoenix, AZ), and one Directorate of Engineering and Housing (Fort Riley, KS) participated in the test. Their participation is appreciated. Appreciation is also expressed to Professsor Charles L. Burton of the Department of Architectural Engineering and Construction Science, Kansas State University, Manhattan, KS, for his assistance in administering the field tests, and to Rosemary Sciwald and Leland Speiers of the Department of Architectural Engineering and Construction Science, Kansas State University, for their contributions to this project. The Technical Editor was Gloria J. Wienke, USACERL Information Management Office.

COL Carl O. Magnell is Commander and Director of USACERL, and Dr. L. R. Shaffer is Technical Director.

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FIELD DEMONSTRATION OF THE ACCEPTANCE TEST PROCEDURE FOR AIR SUPPLY AND DISTRIBUTION SYSTEMS

1 INTRODUCTION

Background

The U.S. Army Construction Engineering Research Laboratory (USACERL) has been investigating methods of improving the installation and operation of heating, ventilating, and air-conditioning (HVAC) systems in new Army facilities. Three interim reports have been published as part of the ongoing effort to improve construction and acceptance testing of new facilities. The first report identified the construction related steps in the Military Construction, Army (MCA) process and discussed problems associated with producing energy-efficient new facilities.[1] The second report recommended improving various steps of the MCA process and documented a strong need for an HVAC acceptance test.[2] Based on those two projects, an acceptance test procedure for air supply and distribution systems was developed and documented.[3]

The purpose of the acceptance test procedure is to determine if air supply and distribution systems in new buildings were installed properly and are operating in an energy-efficient manner. The procedure involves measuring critical energy, flow, pressure, and temperature parameters, and subdivides the air distribution system into four testing categories: fans, ducts, coils, and controls. Each category has a corresponding set of data sheets that includes an inspection checklist and a data recording and calculation section (Appendix A). Data and results from the acceptance tests should be compared with design values and contractor's testing, adjusting, and balancing (TAB) results. Significant discrepancies between these values will indicate possible deficiencies in installation and/or operation. Although the amount of data that can be collected and entered on the data sheets can be very large, there will usually be no need to take extensive data measurements. The checklist portions of the data sheets should be completed, and data collection should be completed for the fan and duct categories. The intended role for the Corps' inspection personnel is to take readings of the system without making any adjustments to it, which could possibly void the warranty. In most situations, only relevant portions of the procedure need be used. As a quality assurance (QA) tool, the procedure is used to check the contractor's TAB work. It is only when the spot checks reveal major discrepancies with the TAB report that more extensive or repeated measurements will be required.

Before this procedure can be recommended for implementation, it has to be field tested on Army buildings to determine how accurate and appropriate it is, and its ease of use. Using funds supplied by the Technology Transfer Test Bed (T^3B) program in Fiscal Years 1988 and 1989 (FY88-89), a broad assessment of the procedure was possible. The T^3B program was initiated by Headquarters, U.S. Army

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[1] Dale Herron, Dahtzen Chu, and Charles Burton, *Preliminary Recommendations for Improving the Construction and Acceptance Testing of Energy-Efficient Facilities*, USACERL Interim Report (IR) E-86/05/ADA169913 (U.S. Army Construction Engineering Research Laboratory [USACERL], June 1986).

[2] Dahtzen Chu, Charles Burton, and Mark Imel, *Identification of Ways to Improve Military Construction for Energy-Efficient Facilities*, IR E-88/02/ADA189632 (USACERL, December 1987).

[3] Dahtzen Chu, Charles L. Burton, and Mark R. Imel, *Development and Initial Evaluation of an Acceptance Testing Procedure for Air Supply and Distribution Systems in New Army Facilities*, IR E-88/11/ADA202580 (USACERL, September 1988).

Corps of Engineers (HQUSACE) to identify, produce, and demonstrate technologies meeting the users' needs. Participation in the T^3B program is voluntary, and participating organizations are reimbursed for their time and effort.

Objective

The objective of this test was to evaluate the ease of use and determine the validity of the acceptance test procedure for air supply and distribution systems in new Army facilities through a field demonstration as part of the T^3B program.

Approach

Four USACE Districts (Mobile, AL; New York, NY; Savannah, GA; and Tulsa, OK) and one Area Office (Phoenix, AZ) participated in the T^3B evaluation. Facilities were tested at Fort Drum, NY; Fort Huachuca, AZ; Fort McClellan, AL; Fort Jackson, SC; Vance Air Force Base (AFB), OK; Maxwell AFB, AL; and Bates Field, AL. Two recently completed and one older facility were also tested at Fort Riley, KS.

Mode of Technology Transfer

It is recommended that the acceptance procedure be incorporated into the USACE PROSPECT Quality Verification: Mechanical I course. The procedure will also be announced in HQUSACE Engineering Improvement Recommendation System (EIRS) Bulletins and construction division newsletters.

2 DESCRIPTION OF THE T^3B TEST

The participating offices and installations were requested to select a new or recently completed facility to test the acceptance test procedure. To be able to determine the validity of the acceptance test results, the contractor must have already conducted TAB activities and submitted a TAB report.

The participants at each test site varied, but included Corps personnel from the District, Area Office, or Resident Office level, and Operations and Maintenance (O&M) personnel from the installation's Directorate of Engineering and Housing (DEH). The expertise of the participants varied; some had excellent knowledge of the measurement instrumentation and others were completely unfamiliar with their functions and use. To prevent delays in testing in case any of the participants were not familiar with the instrumentation, USACERL representatives were present at each site to provide instruction and assistance to ensure that the acceptance test was performed properly. Before each test, the USACERL representatives discussed the purpose of the procedure with the participants. The drawings and specifications for the building were also studied to gather the system design data. The groups also discussed how the Corps verifies or attempts to verify contractor performance.

After the initial discussions, selected portions of the facility's air distribution system were tested using the procedure and instrumentation provided by USACERL. Data were recorded on the acceptance test data sheets and compared with the TAB and design data gathered earlier. An example of a typical set of completed data sheets is contained in Appendix A. During the course of the tests, it was discovered that various hand tools were necessary to carry out the tests. A list of these tools as well as the measurement instrumentation required for the test are listed in Appendix B. Minor modifications were also made to the procedure in response to comments and suggestions from the participants.

3 TEST RESULTS

The purpose of the T^3B tests was to evaluate the validity of the acceptance test procedure for air supply and distribution systems. This requires finding deficiencies, if any, in the procedure in addition to determining if the procedure is easy to use and provides accurate data.

A total of 10 facilities at 8 different installations were visited and tested using the acceptance test procedure. Some of these facilities had just been completed but others were several years old. A summary of notable deficiencies discovered by the procedure at each facility is listed in Appendix C. The usefulness and appropriateness of the procedure can be determined based on evaluations by the participants and on observations made by USACERL representatives.

General Findings

During the tests, readings taken by the participants routinely varied from those listed in the contractor's TAB reports. In some cases, they were within an acceptable margin of difference; in others they were not. Air flow readings from ducts and diffusers were consistently found to be lower than the TAB reports. This difference could be due to measuring instruments that were not properly calibrated. This argument is debatable since different brands and types of instruments were used at the various test sites, and the possibility that all of these instruments were out of calibration is unlikely. Construction deficiencies were also found at each facility tested, often by using just the checklist portion of the acceptance procedure. These deficiencies included missing pressure or flow gauges and connections for taking readings.

Another observation was that the quality and detail of TAB reports varied with location and project. Part of this can be due to the existence of two TAB organizations: Associated Air Balance Council (AABC) and National Environmental Balancing Bureau (NEBB), each of which has their own TAB standards and report formats. Corps of Engineers Guide Specification (CEGS) 15805 requires Contractor test data to be documented on AABC or NEBB forms, or "recognized forms similar to those of AABC or NEBB."[4] A contractor can probably use any TAB format and still be able to comply with the specification. Some contractors will comply with the requirements of AABC or NEBB while others will try to get by with as little work as possible. This potential problem exists because the guide specification does not specifically identify what readings should be included in the TAB report. This cannot be considered a deficiency in the guide specification since it is intended to cover many types of systems, and including too many requirements will make it ponderous. However, the contract specifications should indicate what readings should be made.

Both conventional and electronic instrumentation were used during the tests. For example, both oil-filled and electronic manometers were used to take duct traverses for airflow and pressure readings. The electronic manometers cost more but were easier to set up and read. Using an electronic meter instead of a sling psychrometer for measuring relative humidity was another option. It is often impossible to use a sling psychrometer properly if readings are required inside HVAC equipment. There was no significant difference in the accuracy of electronic vs. conventional instrumentation, but electronic instruments were able to provide more exact readings through their use of digital displays. Some electronic meters,

[4] Corps of Engineers Guide Specification (CEGS)-15805, *Air Supply and Distribution Guide Specification* (U.S. Army Corps of Engineers [USACE], June 1988), Section 21, p. 79.

"multimeters," can perform several different functions. Buying these meters can be somewhat cheaper than buying several different meters. However, many of their functions may not be needed in acceptance testing.

Overall, the electronic meters were easier and less time consuming to use. In some instances, they can also be safer to use. An example of this is electronic tachometers versus contact tachometers. Readings can be taken with electronic tachometers at a reasonably safe distance from high-speed spinning mechanisms while contact tachometers have to be held physically in place to register a reading. The only major disadvantage to electronic instruments is that they are often significantly more expensive than conventional instruments. However, this expense is offset somewhat by their convenience and the consequent reduction in man-hours required to perform the tests. Also, their cost is insignificant when compared to the total cost of a facility's HVAC system and they can be used over and over again.

The availability of original documentation for mechanical room equipment needs to be improved. Participants were unable to get copies of the TAB reports for some of the older buildings tested. Without documentation to compare with acceptance test results, it was extremely difficult to draw any conclusions about the operating performance of the buildings' HVAC systems. In the mechanical room of one building, operations and maintenance manuals were not placed in one central location. Also, some equipment manuals were missing. Besides increasing the difficulty of acceptance testing, missing documentation or manuals may compound the problems for O&M personnel if maintenance or repairs are ever necessary. Documentation should be maintained and organized to be readily available when needed. A similar problem that exists for both new construction and existing facilities is the difficulty in determining where the contractor took TAB readings. Specifications often do not require the contractor to include drawings that show where measurements were made. Consequently, verifying the correctness of readings can be extremely difficult.

During the course of the tests, one potential deficiency in the acceptance test procedure was discovered. When airflow readings are taken at altitudes significantly higher than sea level, they should be adjusted by a correction factor (see Table 1). This factor had not been included in the procedure. The decision to use a correction factor is subjective. For instance, at an elevation of 2700 ft (823.5 m) the error would be 5 percent. This difference may not be large enough to justify the additional effort required to correct the readings. As the altitude increases, this error becomes larger and should be corrected. The tester should also check to see if the TAB contractor has compensated for altitude. Some electronic airflow measuring instrumentation automatically compensates for differences in barometric pressure, so correction is not needed. These units are easier and faster to operate than conventional models, but again, they are also much more expensive.

Another possible problem in the procedure is the coil section. Ideally, coil measurements and calculations should be done on a design day at peak load. This will often not be possible since there is no way of predicting what the weather will be on the day the test is done. One solution may be to induce an artificial load into the system to simulate design peak conditions. This can be done by changing the control settings. If this action is taken, it must be done with the permission and in the presence of the contractor's representative to prevent any potential violation of the warranty. A simpler solution is to change the physical conditions of the thermostat for the area to be tested without actually adjusting the thermostat. Depending on whether cooling or heating conditions are being tested, the hot air from a hair dryer can be blown on the thermostat's sensing element or the element can be immersed in ice water.

One final observation deals with the lack of maintenance on many existing buildings, new as well as old. As an example, the air filters on the air handling units in several buildings tested looked like they had not been changed for a long time; possibly not since the buildings were turned over. In one case, filters were not the right size and there was a gap around the edges. This gap was blocked off with a piece of corrugated cardboard. In another case, one filter's frame and media support grid were still

Table 1

Airflow Correction Facors for Altitude

ALTITUDE IN FEET	CFM CORRECTION FACTOR	ALTITUDE IN FEET	CFM CORRECTION FACTOR	ALTITUDE IN FEET	CFM CORRECTION FACTOR
0	1.000	3200	1.060	9200	1.187
100	1.002	3400	1.064	9400	1.192
200	1.003	3600	1.068	9600	1.196
300	1.005	3800	1.072	9800	1.201
400	1.007	4000	1.076	10000	1.207
500	1.010	4200	1.079	10200	1.210
600	1.011	4400	1.084	10400	1.215
700	1.013	4600	1.088	10600	1.220
800	1.015	4800	1.092	10800	1.225
900	1.017	5000	1.096	11000	1.228
1000	1.019	5200	1.101	11200	1.233
1100	1.021	5400	1.105	11400	1.237
1200	1.022	5600	1.109	11600	1.242
1300	1.024	5800	1.113	11800	1.247
1400	1.026	6000	1.119	12000	1.251
1500	1.028	6200	1.122	12200	1.257
1600	1.029	6400	1.126	12400	1.262
1700	1.031	6600	1.129	12600	1.267
1800	1.034	6800	1.133	12800	1.271
1900	1.035	7000	1.136	13000	1.277
2000	1.037	7200	1.142	13200	1.282
2100	1.039	7400	1.147	13400	1.288
2200	1.041	7600	1.152	13600	1.292
2300	1.043	7800	1.157	13800	1.299
2400	1.045	8000	1.163	14000	1.303
2500	1.046	8200	1.167	14200	1.309
2600	1.049	8400	1.171	14400	1.315
2700	1.050	8600	1.174	14600	1.319
2800	1.053	8800	1.179	14800	1.325
2900	1.054	9000	1.183	15000	1.332
3000	1.056				

Source: Associated Air Balance Council (AABC), *National Standards for Total System Balance*, 4th Ed. (1982).

in place, but all the filter material was gone. Deficiencies such as these can be prevented if the checklist portion of the acceptance test procedure is used on a regular schedule. A related problem is the absence of air filter gauges that measure pressure drops across filters. These gauges will allow quick visual determination of whether filters should be replaced. They are often required in the specification, but are not installed.

Participants' Comments on the T^3B Test

At the end of the acceptance test, each participant was asked to complete a test evaluation sheet (Appendix D) on the acceptance testing procedure. Because so few sites were tested by a relatively small number of participants, the responses cannot be considered representative of all Corps personnel involved with construction. However, the participants are employed in several different disciplines and grade levels; their observations are informative. The complete text of their comments is in Appendix E; the responses are summarized here.

The first two questions requested information on the background of the projects.

3. Did any problems that could impact acceptance testing occur during installation of the air supply and distribution system? If so, describe in detail.

Most participants answered "No." Two comments were made at Fort McClellan about insufficient space in the mechanical room and lack of access to measurement points. Although nothing was written about these problems at the other test sites, they do occur frequently in many facilities. For instance, at a Child Care Center at Fort Drum, the mechanical room was extremely small, making it very difficult to move around in and take measurements.

4. During installation and TAB of the air supply and distribution system, which Corps FOA personnel are responsible for maintaining QA and reviewing the TAB reports respectively?

Most of the responses indicated an engineer, preferably mechanical, at the Area Office level is responsible for reviewing the TAB report. Responsibility for QA varies from base to base, and may be done by a field QA representative.

5. Were the acceptance test procedures or the measuring instrumentation too difficult or time consuming to use? Explain why and identify the procedure and/or the instrument in question.

None of the respondents felt that the procedures were too difficult although they might be time consuming. Finding the correct fittings to take measurements was one task that could cause delays. The exact amount of time and difficulty would vary depending on the complexity of the project, the level of enforcement desired, and experience of the personnel doing the testing.

5a. If the answer to question 4 was affirmative, how can the acceptance test be made easier?

Since none of the participants had any problems with the procedures being too difficult, there were no responses to this question.

5b. Would providing training in performing the procedures and using the instrumentation help?

All the responses to this question were affirmative. Most felt that familiarity with the measurement instruments would be beneficial. Based on USACERL's observations, many construction field inspectors may have difficulty with the procedure without prior training in HVAC concepts and use of

instrumentation. Engineers may also need some training with instrumentation to become proficient in taking readings

5c. Does your office currently possess any TAB instrumentation? If so, identify them, and describe the purpose(s) they are used for.

Most of the field offices did not possess any TAB instrumentation. Some offices do have minor test equipment, but it is insufficient to perform any significant level of testing. One District has some instruments that are used for "trouble-shooting, and investigation and correction of latent defects."

6. How useful or informative was the data provided by the test?

All the respondents commented that the data were very useful in verifying whether the TAB contractor complied with the plans and specifications.

7. Besides the fc omponents tested in this procedure, what other components of the HVAC system should be tested?

Responses included motor efficiencies, controls, variable air volume (VAV) systems, hydronics, chillers, boilers, and exhaust systems. The responses on VAV systems and hydronics were repeated at two test sites, and may indicate a need to develop procedures for these components first.

8. Should acceptance testing be the responsibility of the Resident/Area Offices or the District?

The responses were split between the FOAs and the Districts. One comment indicated that both should be responsible. The Districts and Area Offices felt that Resident and Project Offices probably do not have the time or qualified personnel to do acceptance testing. If an Area Office is well staffed, and has a large area of jurisdiction with many projects, it may be reasonable for that office to assume responsibility.

The participants were also given an opportunity to provide comments on any subjects not covered by the questionnaire. They requested descriptive lists of the instrumentation used in the acceptance procedure, suggested modifications to the procedure, and expressed a need for more training and test equipment.

4 ADDITIONAL RESEARCH EFFORTS

Additional Acceptance Test Procedures

At the end of August 1988, an initial meeting of the HVAC Acceptance Testing Users Group was held at South Atlantic Division, Atlanta, GA, to discuss the concept of acceptance testing of HVAC systems. The attendees included Corps personnel with mechanical systems expertise from HQUSACE, Division, District, Area Office, and installation DEH levels. A decision was made at the meeting to develop additional acceptance test procedures for VAV systems, boilers, chillers, hydronic systems, and exhaust systems because these five areas were considered to be the most prone to problems during installation and operation of HVAC systems. Information gathering on these five HVAC subsystems was initiated at the start of FY89. Development of procedures is scheduled to begin in FY91 and be completed and tested by the end of FY92. Attendees also decided to incorporate the Acceptance Test Procedure for Air Supply and Distribution Systems into the USACE PROSPECT Quality Verification: Mechanical I course. This course covers preparatory, initial, followup, and final verification techniques for equipment and material, and testing requirements for common mechanical systems. The audience for this course includes engineers, engineering technicians, and construction representatives with mechanical quality assurance responsibilities. Including this procedure in the PROSPECT course will be coordinated with the course instructors, several of whom are members of the users group.

Extended Performance Testing

The concept of "extended performance testing" is relevant to acceptance testing of HVAC systems. The acceptance test procedure demonstrated by this program involves one-time, onsite measurements of HVAC system parameters. Although these measurements can reveal many problems in an HVAC system, they may not point out improper system performance over an extended length of time. The system may provide comfortable environmental conditions even though it isn't operating efficiently. Although deficiencies may not be noticed by the occupants, they can often have a dramatic impact on the system's energy consumption. Personnel can use simple and relatively inexpensive data acquisition equipment to verify the system's efficiency. The potential exists to use this technology for qualitative performance testing to complement the quantitative acceptance testing procedures.

Improper system performance is being identified by building monitoring experiments being carried out by USACERL at Fort Riley, KS. The intent of these ongoing experiments is to accurately quantify building energy consumption. To accomplish this, highly accurate instrumentation is being used. Substantial onsite calibration was necessary. As the projects progressed, data was collected at additional points to determine the system performance more accurately. These data were often obtained with low cost instrumentation such as pressure transducers, thermocouples, or electronic relays. In most cases, valuable insight into the system's performance was gained using these low cost instruments. The following paragraphs discuss deficiencies discovered by the instrumentation.

Pressure Transducers

The first example involves a pneumatic control, VAV air-handling system located in a single story administration building of approximately 12,500 sq ft (1161 m^2). Improper operation of a damper was discovered through use of an air pressure transducer on the control line. The damper modulates the ratio of return air and outside air brought into the air handler. The default setting for this damper would be for minimum outside air. As air pressure is increased, the damper opens to allow more outside air to be introduced. At the time of the deficiency, the outside air temperature was 30 °F (-1 °C). Data taken by

the pressure transducer shows the air pressure applied to the damper over a period of 150 seconds. Figure 1 shows that the damper is modulating through a full stroke from maximum to minimum outside air in about a 25-second cycle. This could not be detected inside the building as the air was well mixed and heated before entering the occupied spaces. The effect on energy consumption would be substantial because of the unnecessary load introduced. The life of the damper would also be shortened by the continuous modulation.

Thermocouples

A reset schedule based on outside air temperatures is another system performance characteristic easily analyzed through low cost data acquisition. The example given is for a 12,000 sq ft (1115 m^2) administration building with a hot water, perimeter heating system. The only control is a reset schedule modulating the hot water supply temperature based on the outside air temperature. As the outside air temperature decreases, the water supply temperature should increase, and vice versa. Figure 2 shows energy consumption and hot water supply (HWS) temperature. Values are shown for before and after a recalibration of the control system's outside air sensor. Before calibration, the system's control remained relatively constant, showing no response to fluctuating outside temperatures. Energy consumption and HWS temperature were relatively constant. After calibration, energy consumption and HWS temperature fluctuated as the outside air temperature changed. This information could have been found easily with one thermocouple measuring outside air temperature and another, attached to the hot water pipe, monitoring the water temperature. Accurate water temperatures are not critical for this purpose. What is important is the response of the control system (i.e., varying water temperature) to changing outside temperatures.

Electronic Relays

The on/off status of a device and the total run time can be easily monitored with an electronic relay. Figure 3 shows the run time of a makeup air unit in a tactical equipment shop. The number of minutes the unit is on is given hourly for a 2-day period. The unit is supposed to run during duty hours to provide ventilation, and be off at night. The figure shows that the unit was not on until about 1600 hours on the first day, then remained on. Two problems are evident. First, ventilation was not provided during the duty hours of the first day. This may be due to the occupants turning the unit off, or by a faulty control clock. The second problem occurs once the unit begins running. Excessive energy use resulted from the unit running constantly. Once the unit came on, it should have automatically shut down during the nonduty, nighttime hours.

Many other examples of inefficient system operation can be found with simple instrumentation. Often they are subtle and will not be detected in a short visit. The dynamic performance of a system can be monitored passively or actively. A passive approach would be similar to the examples given above. Certain data points are monitored over a short period of time where varying conditions should cause the controls to adjust the system's operation. An active test would involve imposing certain conditions on the controls and watching how the system responds. A temperature sensor may have hot air blown across it or be immersed in cold water to simulate summer or winter conditions. It is also possible to induce a given pressure into a pneumatic control line to see how the controlled device reacts.

Automated Acceptance Testing

Simple instrumentation can be integrated into an interactive and user-friendly automated system, which can further reduce the amount of time and effort required to verify correct installation and operation of an HVAC system. The automated system would require either permanent or temporary sensors to be

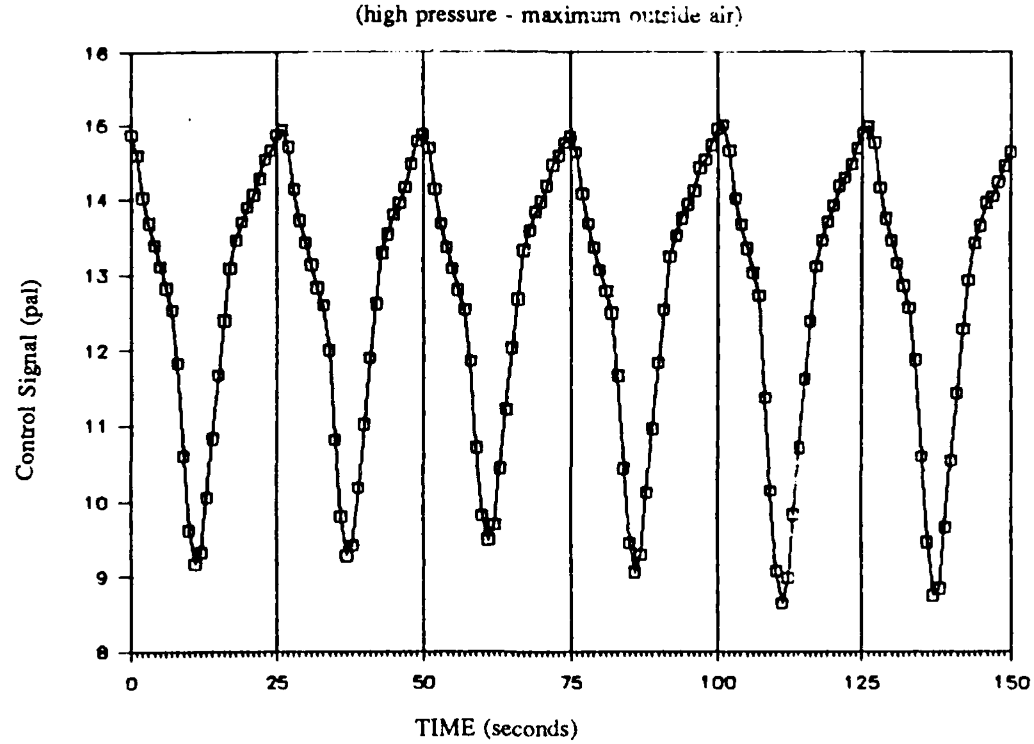


Figure 1. Outside air damper control signal.

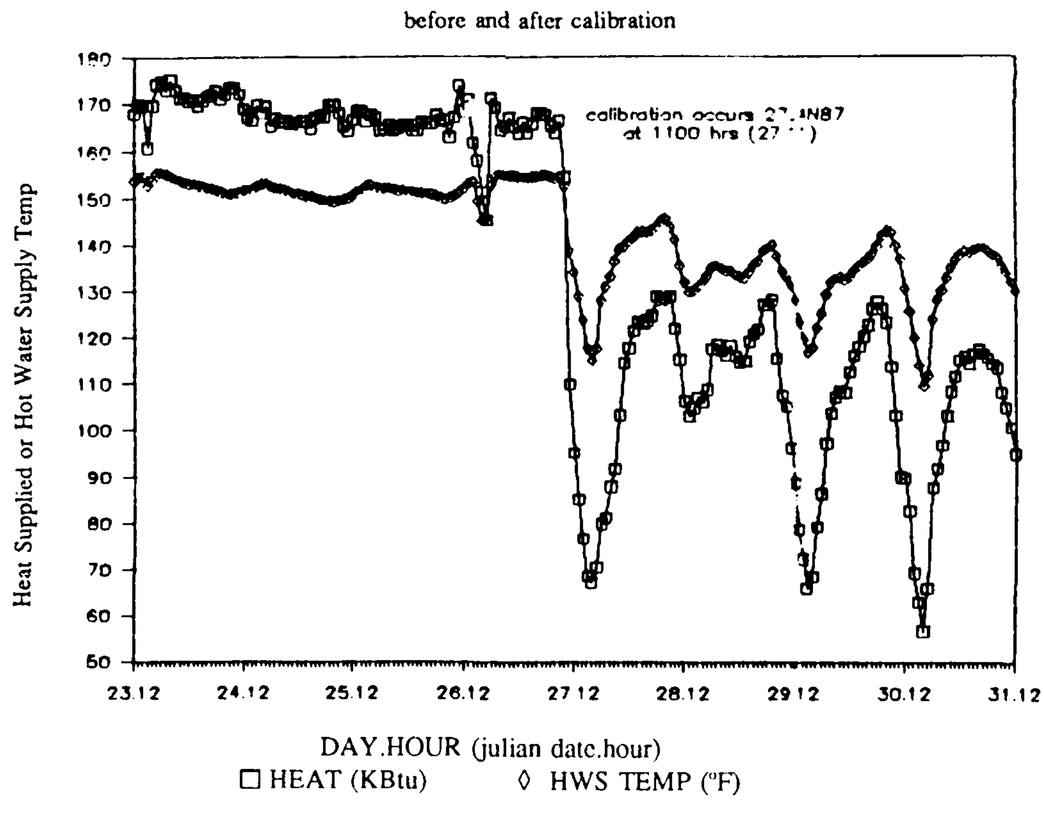


Figure 2. Heat supplied and hot water supply temperature.

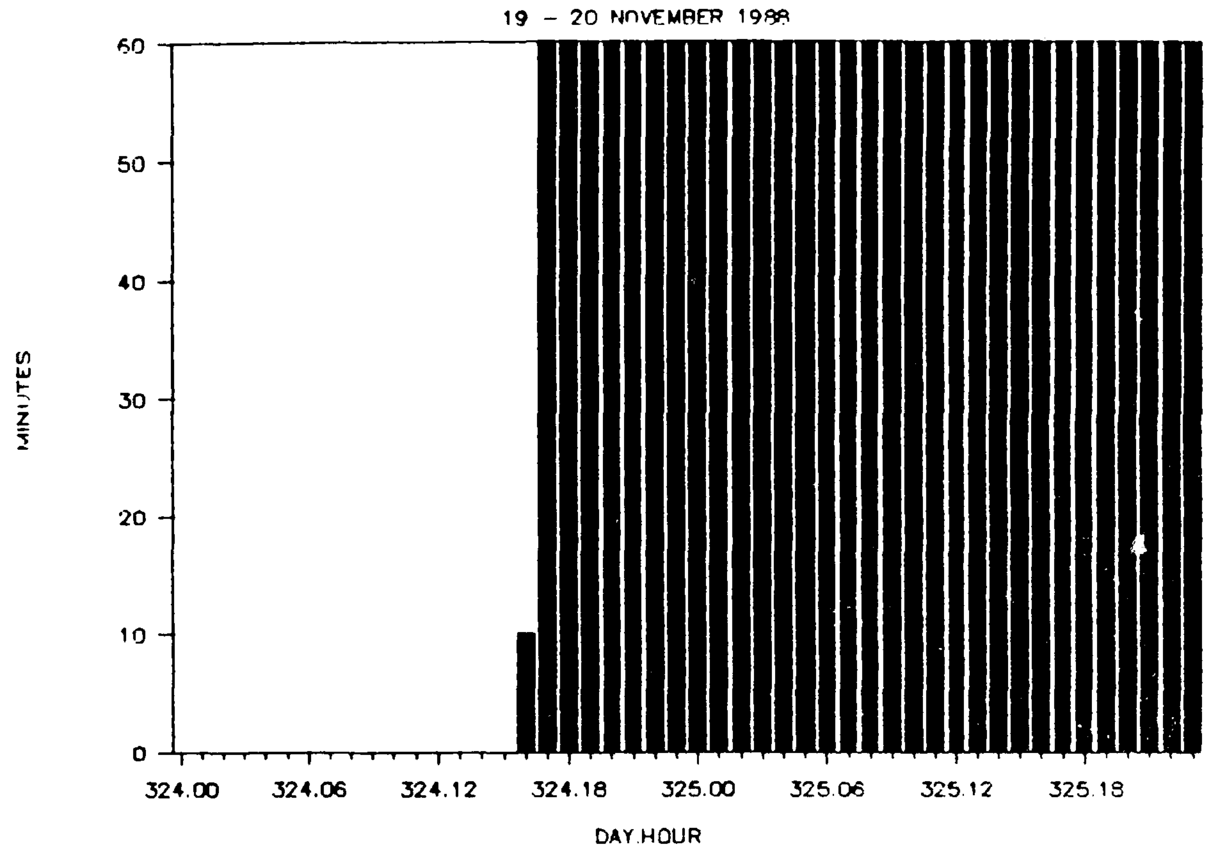


Figure 3. Run time of makeup air unit.

installed in selected areas or components of the HVAC system. The sensors would all report to one central data acquisition center (i.e., a portable computer). After the HVAC system has been started, the inspector would turn on the computer, activate the sensors, and allow the automated system to operate for a predetermined interval to verify whether the selected portions of the HVAC system are operating properly. Any deficiencies should be displayed on the computer screen immediately. The automated system should also be capable of being hooked up to the HVAC system's controls and be able to verify the sequence of operation.

After acceptance testing procedures for individual HVAC components and the system as a whole have been developed, field tested, and proven effective, an interactive and user-friendly automated system can be developed. Such an automated system should also be field tested and demonstrated after development.

5 CONCLUSIONS AND RECOMMENDATIONS

Overall, the participants were supportive of the concept of acceptance testing. Their most common concern was acquiring the resources to perform this function. Many Corps offices, from field project offices on up, do not have the staffing and/or funding to perform acceptance testing regularly. Lack of funding to purchase measurement instrumentation is another constraint. These issues will have to be resolved before acceptance testing can assume a major role in the Corps' QA program.

The acceptance test procedure for air supply and distribution systems will be revised and updated to reflect the results of the T^3B tests and the participants' comments. It will then be incorporated into the USACE PROSPECT Quality Verification: Mechanical I course as a QA tool. This will help expose Corps construction representatives to the concept of acceptance testing and allow them to better understand how to monitor the TAB contractor's work. The tests also demonstrated that the procedure can be adapted to different facility types. Development of the procedures should not be considered final. Revisions/updates should be made after periodic review to prevent the procedure from becoming obsolete.

To increase the effectiveness of the procedure, the following recommendations are made:

1. Test sections in Corps of Engineers Guide Specifications should state that drawings or schematics are required to be submitted with TAB reports to make it easier to verify contractor TAB results. The drawings or schematics must identify and number the location of all measurement points. Besides making verification easier to perform, this will also serve notice to the contractor that the measurements will be checked.

2. Contract specifications should include a requirement for the contractor to place a copy of the TAB report in the mechanical room along with the equipment operations and maintenance manuals.

3. All operations and maintenance manuals should be placed together in one central location in the mechanical room. A cabinet next to the control panel would be a good location.

Many Corps offices do not possess sufficient measurement instrumentation for acceptance testing purposes. Districts and Area Offices with high levels of construction activity need all necessary instrumentation. Responsibility for acceptance testing should be assigned to qualified construction and engineering personnel. If necessary, additional training can be provided.

The following steps to use the procedure as an O&M tool should also be considered:

1. Establish a regular maintenance schedule that follows the checklist portion of the acceptance test procedure.

2. Improve the procedure for DEH use by adding information on what to do when HVAC system components are not operating properly. The current version of the procedure does not do this since it is supposed to be used only to verify the information contained in the TAB report, not to make corrections to the system operation. A possible solution may be to develop a troubleshooting matrix that could be used in conjunction with the procedure. The matrix could contain a list of common problems along one axis and referrals to the procedure on the other axis. Potential solutions can also be listed.

Future work should consider the use of simplified short-term data acquisition to monitor performance of HVAC system components to discover inefficient operation.

APPENDIX A:
EXAMPLE OF A COMPLETED SET OF ACCEPTANCE TEST DATA SHEETS

FAN DATA WORKSHEET

PROJECT: CHEMICAL SCHOOL AUDITORIUM MODERNIZATION

EQUIPMENT LOCATION: MECHANICAL ROOM

FAN TYPE: CENTRAL STATION AHU (FC CENT.)

SYSTEM CHECKS:

	Ready yes	Ready no	Date checked
1. Nameplate data	✓		8/31/88
2. Rotation (in correct direction)	✓		
3. Wheel clearance and balance	✓		
4. Bearing and motor lubrication			
5. Drive alignment and belt tension	✓		
6. Drive set screws tight			
7. Belt guard in place	✓		
8. Flexible duct connector alignment	*		
9. Starters and disconnect switches	✓		
10. Electrical service and connections	✓		
11. Fan inlet and discharge	✓		
12. Air filters	✓		

NOTE * - DOES NOT HAVE

DUCT TRAVERSE WORKSHEET:

Use this worksheet to calculate volumetric airflow at fan outlet or zone. Divide duct to be measured into 16 blocks. Use manometer and pitot tube to take readings of velocity pressure at the centerpoint of each block. Convert velocity pressure to velocity using attached table, and mark down in the appropriate space below.

X 18

SUPPLY *
Zone number: 18/24

24 Y

	X/8	X/4	X/4	X/4		
Y/8	566 .02	801 .04	694 .03	566 .02		
Y/4	981 .06	981 .06	694 .03	694 .03		
Y/4	981 .06	1060 .07	896 .05	694 .03		
Y/4	896 .05	981 .06	896 .05	694 .03		

Note: If the maximum distance between traverse points is greater than 6", expand the duct traverse diagram as necessary by using the shaded blocks of the diagram.

$$\text{Average Velocity (fpm)} = \frac{\text{Sum of Readings}}{\text{Number of Readings}} = \frac{13{,}075}{16}$$

$$\text{Net Area (ft}^2\text{)} = \frac{\text{(Duct Width)} * \text{(Duct Height)}}{144} = \frac{18 \times 24}{144}$$

Volumetric Air Flow (cfm) = (Average Velocity) * (Net Area)

Average Velocity	* Net Area	= Volumetric Air Flow
817	. 3	2,451

DESIGN CFM = 3330 (FROM DWGS)

$$\text{DESIGN VELOCITY} = \frac{3330}{\frac{18 \times 24}{144}} = 1110 \text{ fpm}$$

* REFER TO COPY OF FLOOR PLAN AND MECH. ROOM PLAN FOR TRAVERSE LOCATIONS.

DUCT TRAVERSE WORKSHEET:

Use this worksheet to calculate volumetric airflow at fan outlet or zone. Divide duct to be measured into 16 blocks. Use manometer and pitot tube to take readings of velocity pressure at the centerpoint of each block. Convert velocity pressure to velocity using attached table, and mark down in the appropriate space below.

X 18

X/8 | X/4 | X/4 | X/4

SUPPLY *
Zone number: 18/18

18 Y

Y/8 | Y/4 | Y/4 | Y/4

694 .03	801 .04	801 .04	566 .02		
896 .05	981 .06	1060 .07	896 .05		
981 .06	1060 .07	1060 .07	981 .06		
694 .03	896 .05	981 .06	896 .05		

Note: If the maximum distance between traverse points is greater than 6", expand the duct traverse diagram as necessary by using the shaded blocks of the diagram.

$$\text{Average Velocity (fpm)} = \frac{\text{Sum of Readings}}{\text{Number of Readings}} = \frac{14244}{16}$$

$$\text{Net Area (ft}^2\text{)} = \frac{\text{(Duct Width)} * \text{(Duct Height)}}{144} = \frac{18 \times 18}{144}$$

Volumetric Air Flow (cfm) = (Average Velocity) * (Net Area)

Average Velocity *	Net Area =	Volumetric Air Flow
890	2.25	2003

DESIGN CFM = 2520 (FROM DWGS)

$$\text{DESIGN VELOCITY} = \frac{2520}{\frac{18 \times 18}{144}} = 1120 \text{ fpm}$$

* REFER TO COPY OF FLOOR PLAN AND MECH. ROOM PLAN FOR TRAVERSE LOCATIONS.

DUCT TRAVERSE WORKSHEET:

Use this worksheet to calculate volumetric airflow at fan outlet or zone. Divide duct to be measured into 16 blocks. Use manometer and pitot tube to take readings of velocity pressure at the centerpoint of each block. Convert velocity pressure to velocity using attached table, and mark down in the appropriate space below.

X 24

RETURN *

Zone number: 24/24

Y 24

	X/8	X/4	X/4	X/4		
Y/8	550 .02	00 25	550 .02	550 .02		
Y/4	650 .025	70 2	500 .015	500 .015		
Y/4	700 .03	77 .025	550 .02	600 .025		
Y/4	700 .035	700 .035	650 .03	650 .025		

Note: If the maximum distance between traverse points is greater than 6", expand the duct traverse diagram as necessary by using the shaded blocks of the diagram.

$$\text{Average Velocity (fpm)} = \frac{\text{Sum of Readings}}{\text{Number of Readings}} = \frac{9650}{16}$$

$$\text{Net Area (ft}^2\text{)} = \frac{\text{(Duct Width)} * \text{(Duct Height)}}{144} = \frac{24 \times 24}{144}$$

Volumetric Air Flow (cfm) = (Average Velocity) * (Net Area)

Average Velocity	* Net Area	= Volumetric Air Flow
603	4	2412

DESIGN CFM = 3600 (FROM DWGS)

$$\text{DESIGN VELOCITY} = \frac{3600}{\frac{24 \times 24}{144}} = 900$$

* REFER TO COPY OF FLOOR PLAN AND MECH. ROOM PLAN FOR TRAVERSE LOCATIONS.

DUCT TRAVERSE WORKSHEET:

Use this worksheet to calculate volumetric airflow at fan outlet or zone. Divide duct to be measured into 16 blocks. Use manometer and pitot tube to take readings of velocity pressure at the centerpoint of each block. Convert velocity pressure to velocity using attached table, and mark down in the appropriate space below.

X 36

RETURN *
Zone number: 36/12

Y 12

	X/8	X/4	X/4	X/4		
Y/8	450 .05	450 .05	450 .05	450 .05		
Y/4	450 .05	450 .05	450 .05	450 .05		
Y/4	450 .05	450 .05	400 .00	400 .00		
Y/4	400 .00	450 .05	450 .05	450 .05		

Note: If the maximum distance between traverse points is greater than 6", expand the duct traverse diagram as necessary by using the shaded blocks of the diagram.

Average Velocity (fpm) = $\frac{\text{Sum of Readings}}{\text{Number of Readings}} = \frac{7050}{16}$

Net Area (ft^2) = $\frac{\text{(Duct Width) * (Duct Height)}}{144} = \frac{36 \times 12}{144}$

Volumetric Air Flow (cfm) = (Average Velocity) * (Net Area)

Average Velocity	* Net Area	= Volumetric Air Flow
440	3	1320

DESIGN CFM = 2800 (FROM DWGS)

DESIGN VELOCITY = $\frac{2800}{\frac{36 \times 12}{144}}$ = 933 fpm

* REFER TO COPY OF FLOOR PLAN AND MECH. ROOM PLAN FOR TRAVERSE LOCATIONS

DUCT SYSTEM DATA:

Zone No. 1 * SUPPLY	Design Airflow cfm	Temp T_z	TAB Airflow cfm	Temp T_z	Actual Airflow* cfm	Temp T_z
Diffuser No.	cfm	T_d	cfm	T_d	cfm	T_d
1	260		240		210	
2	270		270		280	
3	270		280		300	
4	250		240		150	
5	280		290		255	
6	280		290		270	
7	360		345		290	
8	360		370		360	
9	360		380		280	
10	360		365		415	
11	360		350		250	
12	360		340		410	
13	360		365		290	
14	360		380		410	
15	360		345		250	
16	360		370		360	
17	360		370		260	
18	360		370		340	
19	360		360		220	
20	360		365		290	
Total cfm	6650		6685		5890	

*Use duct traverse worksheet (Fan Data, page 2) to calculate airflow.

NOTE: * REFER TO COPY OF FLOOR PLAN FOR DIFFUSER LOCATION

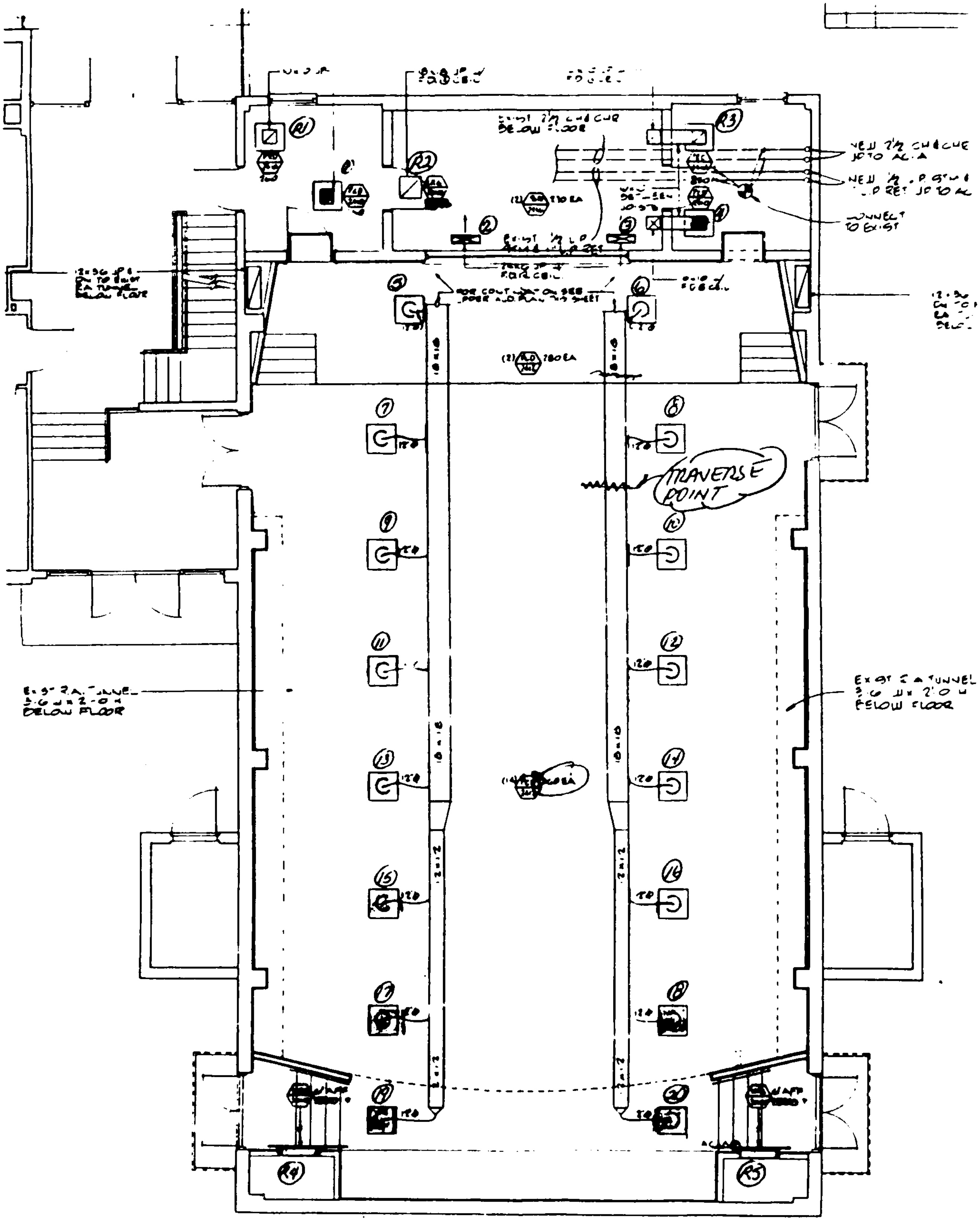
DUCT SYSTEM DATA:

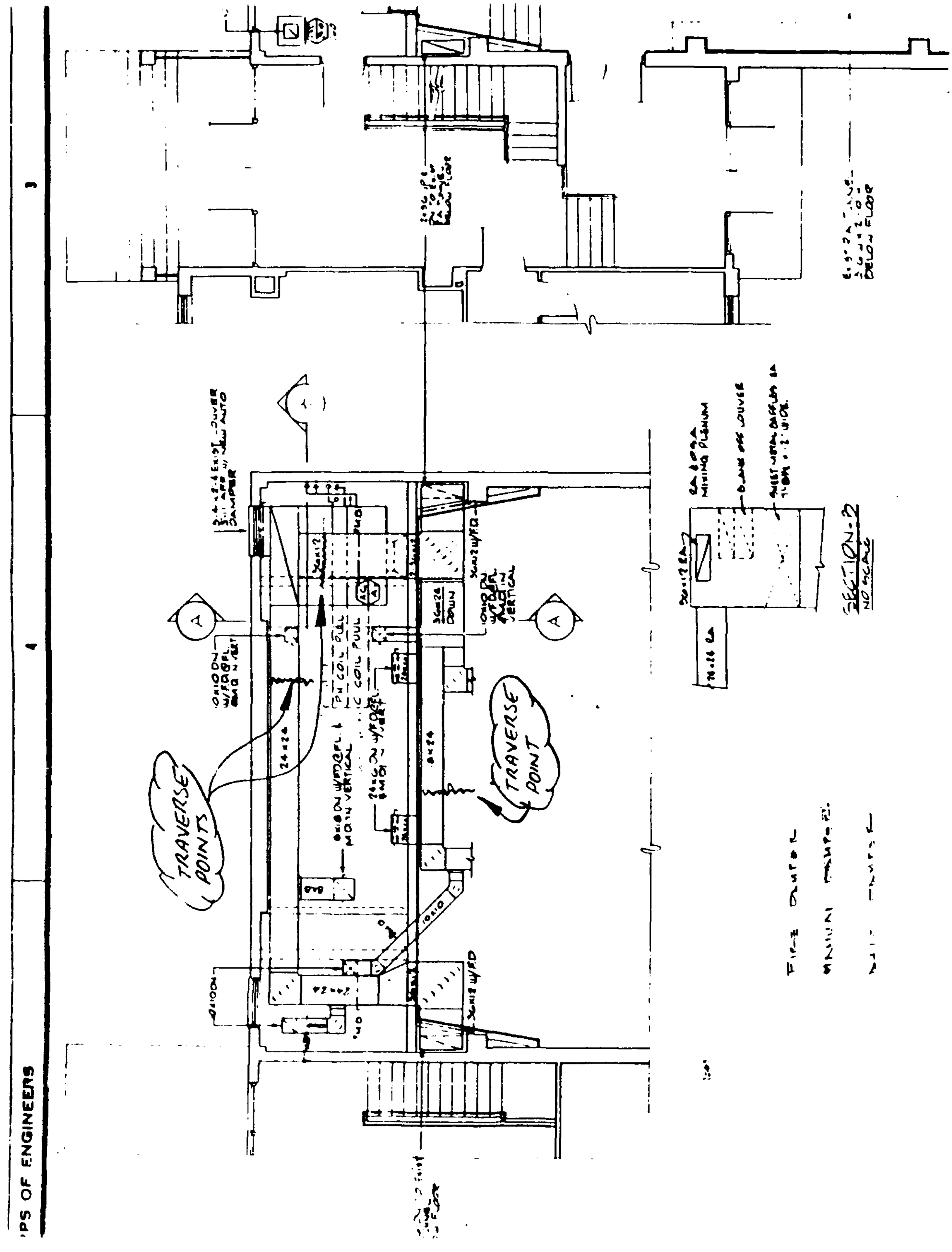
Zone No. / RETURN	Design Airflow cfm	Design Temp T_z	TAB Airflow cfm	TAB Temp T_z	Actual Airflow* cfm	Actual Temp T_z
Diffuser No.*	cfm	T_d	cfm	T_d	cfm	T_d
R1	260		270		225	
R2	540		535		620	
R3	250		260		25	
R4	2800		1640		**	
R5	2800		1780		**	
Total cfm						

*Use duct traverse worksheet (Fan Data, page 2) to calculate airflow.

NOTE: *REFER TO COPY OF FLOOR PLAN FOR GRILLE LOCATION.

** COULD NOT MEASURE DUE TO RESTRICTED GRILLE.


TRAVERSE POINT
CONNECT TO EXIST
R1
R2
R3
R4
R5



PS OF ENGINEERS
TRAVERSE POINTS
TRAVERSE POINT
24x24
SECTION-2
NO SCALE

PER DESIGN
AS SUBMITTED

FAN SYSTEM DATA:

	Design	TAB	Actual
Fan Motor Nameplate Amps A_{np}	10.6		10.6
Fan Motor Nameplate Voltage V_{np}	208/3/60		208/230 460
Fan Motor Nameplate Horsepower HP_{np}	5 / 3		3
Fan Motor Operating Amps A_{op}	N/A		6.5/6.5 6.5
Fan Motor Field Checked Voltage V_{fc}	N/A		220/220 220
Fan Motor rpm rpm	1750		1740
Fan rpm rpm	650		640
Volumetric Air Flow (cfm) cfm	6640		
Total Airstream Pressure (P_t) in. wg	2.25 TOT 1.25 SUCT		.06 DISCH 1.15 SUCT
Static Airstream Pressure (P_s) EXT. ~~inlet~~ in. wg	0.40		
~~discharge~~	N/A		

1.21 TOTAL

NOTE: * USING FLOW FROM DUCT SYSTEM DATA (5890)
** " " " TRAVERSE (5534)

FAN CALCULATIONS:

	Design	TAB	Actual
Corrected Full Load Amps (CFLA) $CFLA = (A_{np} * V_{np})/V_{fc}$	N/A		10.02
Approximate Brake Horsepower (BHP_a) $BHP_a = (A_{op}/CFLA)(HP_{np})$ HP	N/A		1.95
Total Air Horsepower (AHP_t) $AHP_t = (cfm * P_t)/6356$ HP	2.35		* 1.12
Static Air Horsepower (AHP_s) $AHP_s = (cfm * P_s)/6356$ HP	0.42		NOT MEASURED
Static Efficiency = AHP_s/BHP_a %	N/A		NOT MEASURED
Total Efficiency = AHP_t/BHP_a %	N/A		* 58

** 1.05

** 54

Note: Use results of calculations to plot a point on the performance curve (provided by the manufacturer) that the fan is operating at. This should determine if the fan is operating at an acceptable efficiency or not (acceptability ranges should also be provided by the manufacturer.)

RECOMMENDED ACTIONS: ______________________

DUCT DATA WORKSHEET

PROJECT: CHEMICAL SCHOOL AUDITORIUM MODERNIZATION

DUCT TYPE: NOT NECESSARY ~~(low)(high) Velocity~~ (low)(medium)(high) Pressure

SYSTEM CHECKS:

	Ready yes	Ready no	Date checked
1. Outside air intake, return, and exhaust air dampers in proper position	✓		8/31/89
2. System volume dampers and fire dampers open and accessible	✓		
3. Access doors closed and tight	✓		
4. Terminal units, registers, and diffusers fully open and set	✓		
5. Turning vanes in square elbows	✓		
6. Ductwork sealed as required	✓		
7. Coils, duct heaters, terminals inspected for leakage	✓		
8. Air shafts and openings as required	✓		
9. Windows and doors installed and closed	✓		
10. Ceiling plenums installed and sealed	✓		

DUCT CALCULATIONS:

$$\text{Airflow Efficiency (AFE)} = \frac{\text{Total Volumetric Airflow for Diffusers}}{\text{Volumetric Airflow at Zone Inlet}} * 100\ \%$$

	Design	TAB	Actual
AFE			

Note: If airflow efficiency is less than 90%, duct leakage or blockage should be located.

Air Temperature Difference = $T_d - T_z$ N/A

where: T_d = Air Temperature at Diffuser
T_z = Air Temperature at Zone Inlet

Diffuser Number										
$T_d - T_z$										

Note: This is calculated for each diffuser. If the Air Temperature Difference is more than 10 percent of the Zone Inlet Air Temperature, the source of heat loss or heat gain must be determined and corrected.

RECOMMENDED ACTIONS:______________________________

COIL DATA WORKSHEET

PROJECT: CHEMICAL SCHOOL AUDITORIUM MODERNIZATION

COIL TYPE: ______

SYSTEM CHECKS:

	Ready yes	no	Date checked
1. Size and rows	*		9/1/83
2. Fin spacing and condition	*		
3. Obstructions and/or debris	✓		
4. Piping leakage	✓		
5. Correct piping connections and flow	✓		
6. Air vents	✓		
7. Airflow and direction	✓		
8. Coil placed in proper direction	✓		
9. Valves open or set	✓		

* COULD NOT DETERMINE

PUMP SYSTEM DATA:

		Design	TAB	Actual
Pump Motor Nameplate Amps	A_{pnp}			
Pump Motor Nameplate Voltage	V_{pnp}	N/A		
Pump Motor Nameplate Horsepower	HP_{pnp}			
Pump Motor Operating Amps	A_{pop}			
Pump Motor Field Checked Voltage	V_{pfc}			
Pump Motor rpm	rpm			
Total System Pressure Drop (measured at pump)	ft hd			

COIL SYSTEM DATA:

Air Measurements:		Design	TAB	Actual
Airflow rate (cfm)	cfm	6640	6740 +L	5890 FROM DUCT SYSTEM DATA
Entering dry bulb temp (T_{endb})	deg F	76.2	76.2	74
Entering wet bulb temp (T_{enwb})	deg F	63.5	65.6	67.5
From psychrometric chart: Entering humidity ratio (HR_{en})	g/lbm	67.5		90
Entering pressure (P_{en})	in wg			
Leaving dry bulb temp (T_{lvdb})	deg F	63.6	57.1	65
Leaving wet bulb temp (T_{lvwb})	deg F	59	56.2	60.5
From psychrometric chart: Leaving humidity ratio (HR_{lv})	g/lbm	67		72
Leaving pressure (P_{lv})	in wg			
Change in dry bulb temp (ΔT_{db}) $\Delta T_{db} = T_{endb} - T_{lvdb}$ (cooling) $\Delta T_{db} = T_{lvdb} - T_{endb}$ (heating)	deg F	12.6	19.1	13.5
Change in humidity ratio (Δg) $\Delta g = HR_{en} - HR_{lv}$	g/lbm	0.5	30.5 - 24.4 6.1	18
Pressure drop (PD_{air}) $PD_{air} = P_{en} - P_{lv}$	in wg			

Water Measurements:		Design	TAB	Actual
Water flow rate (gpm)	gpm	40	39.1	
Entering temperature (EWT)	deg F	45	49.4	49
Entering pressure (EWP)	in wg			
Leaving temperature (LWT)	deg F	58	58.7	56
Leaving pressure (LWP)	in wg			
Change in water temp (ΔT_{water}) ΔT_{water} = EWT - LWT (cooling) ΔT_{water} = LWT - EWT (heating)	deg F	13	9.3	7
Pressure drop (PD_{water}) PD_{water} = EWP - LWP	in wg			110 in wg

NOTE: * USING FLOW FROM DUCT SYSTEM DATA 5894 cfm
** " " " TRAVERSE 5534 cfm

COIL CALCULATIONS:

Air:	Design	TAB	Actual	
Sensible Heat (Q_s) BtuH $Q_s = 1.08 * cfm * \Delta T_{db}$	90,357	139,032	* 85,876	** 80,685
If testing for cooling conditions, also calculate the following:				
Latent Heat (Q_l) BtuH $Q_l = 0.7 * cfm * \Delta g$	2,324	28,779	74,214	69,728
Total Heat (Q_t) BtuH $Q_t = Q_s + Q_l$	92,681	167,811	160,090	150,413

For Water (liquid) Coils:	Design	TAB	Actual	
Heat Transfer (Q_{water}) $Q_{water} = 500 * gpm * \Delta T_{water}$ BtuH	260,000	181,815	140,000	ASSUME 40 gpm
Total Coil Efficiency (EFF_{tot}) % $EFF_{tot} = Q_t / Q_{water}$ (cooling) $EFF_{tot} = Q_s / Q_{water}$ (heating)	36	92	114	

For Direct Expansion Coils:	Design	TAB	Actual
Coil Heat Transfer (Q_{coil}) BtuH per manufacturer		N/A	
Total Coil Efficiency (EFF_{tot}) % $EFF_{tot} = Q_t / Q_{coil}$			

RECOMMENDED ACTIONS: ____________________

CONTROLS DATA WORKSHEET

PROJECT: ______________________________

CONTROLS LOCATION: ______________________________

CONTROLS TYPE: ______________________________

SYSTEM CHECKS:

	Ready yes	Ready no	Date checked
1. Controllers installation and location	✓		
2. Sensing elements installation and location		✓	
3. Controller set point	✓		
4. Connections between sensing elements, controllers, and controlled devices	✓		
5. Dampers and valves	✓		
6. Pneumatic operating air pressure	✓		
7. Air dryer and filter			
8. Electric/electronic operating voltages			
9. Safety controls installation and location	✓		
10. Pneumatic lines, electric wires and devices	✓		
11. Change in pneumatic supply air pressure (day/night, summer/winter)			

RECOMMENDED ACTIONS: ______________________________

____

____

____

____

____

APPENDIX B: MINIMUM REQUIRED INSTRUMENTATION AND TOOLS

During the course of the T^3B tests, the following tools and instrumentation were found to be necessary for performing acceptance testing:

1. Instrumentation
   Manometer and Pitot Tube - used in conjunction to measure volumetric airflow and airstream pressure
   Voltmeter - measures electric voltages and currents
   Tachometer - measures fan and fan motor speed
   Flow Measuring Hood or Cone - measures volumetric airflow at individual diffusers
   Thermometer - measures air temperature
   Differential Pressure Gauge - measures fluid flow pressure drop
   Psychrometer - measures relative humidity

2. Tools
   Adjustable Wrenches, 6- and 8-in.
   Channel-lock Pliers
   Duct Tape
   Hammer and Punch
   Nut Driver Set
   Portable Rechargeable Drill, with bits up to 1/2 in.
   Reamer, 1/2 in.
   Screwdriver, Phillips and slotted
   Tape Measure
   Calculator
   Flashlight

Not all this equipment will be needed all the time, but these are the minimum required to be able to respond to differing site conditions.

APPENDIX C: SUMMARY OF NOTABLE DEFICIENCIES

The following is a summary of notable findings at the various test sites:

Fort Drum, NY

Child Care Center - The test indicated airflow leakage may be occurring at the connections between ducts and diffusers. Some airflow readings were as low as 66 percent of design. Circuit setters that were required on the hydronic piping were not installed even though they were specified.

Fort Huachuca, AZ

Package Beverage Center - Diffuser airflow readings taken by us were consistently lower than those taken by the TAB contractor. The specifications did not require a traverse to be taken off the single main supply duct. Airflow readings should be compensated for altitude.

Fort Jackson, SC

Youth Activity Center - The supply air from one unit was approximately 60 percent of what was listed in the TAB report. The fan belt in one unit was broken and the belt in another one may soon break (the building is only 2 months old).

Fort McClellan, AL

Chemical School Auditorium Modernization - Airflow readings were consistently different from those listed on the TAB report. Many construction deficiencies were also found.

Fort Riley, KS

Dental Clinic - A laboratory exhaust fan was rotating backwards, thereby providing insufficient ventilation to the lab.

Battalion Headquarters - Original TAB results were unavailable for comparison. Airflows were as low as 82 percent of design. Filters were incorrectly sized or defective. Air filter gauges were not installed as required. Design deficiencies were found.

Bates Field, AL

FAA Control Tower - Controls for relief dampers were out of adjustment.

Maxwell AFB, AL

Telephone Exchange Building - Air filters were very dirty. Coil capacities were not tested as required by the specifications. The relief damper for one air handling unit did not operate correctly.

Vance AFB, OK

Mission Support Center - Some airflows were as low as 33 percent of what was listed in the preliminary TAB report. The computer room humidifier was scaling badly. This could be due to design. Air filter gauges were not installed as required.

APPENDIX D: HVAC ACCEPTANCE TEST PROCEDURE TEST PLAN AND EVALUATION SHEET

The U.S. Army Construction Engineering Research Laboratory (USACERL) has developed an acceptance test procedure for air supply and distribution systems in newly constructed Army facilities. The purpose of the new procedure is to verify that the systems were installed correctly and operating as designed. To assure that this procedure is accurate and useful, FOA or District personnel must field test the procedure on an actual new Army facility.

The FOA or District will be asked to select a new facility currently nearing completion of construction. The field test of the acceptance testing procedure cannot be undertaken until the new facility's air supply and distribution system has been fully installed, and tested, adjusted, and balanced (TAB). Completion of the acceptance test procedure will confirm or disprove the TAB results. This will help the Corps ensure that it is accepting properly installed, energy-efficient systems.

The procedure shall be performed using the tests developed by USACERL. All necessary funding and required measuring instrumentation will be provided by USACERL. Design and TAB data shall be provided by the FOA or District. Data produced by the procedure shall be recorded on the data worksheets included with the procedure. After the procedure has been completed, it should be evaluated using the attached report forms. Relevant sheets of the mechanical drawings should be included for reference.

HVAC ACCEPTANCE TESTING PROCEDURES EVALUATION

1. Project: ____________________

2. Location: ____________________

3. Did any problems that could affect acceptance testing occur during installation of the air supply and distribution system? If so, describe in detail.

4. During installation and TAB of the air supply and distribution system, which Corps FOA personnel are responsible for maintaining QA and reviewing the TAB reports respectively?

5. Were the acceptance test procedures or the measuring instrumentation too difficult or time consuming to use? Explain why and identify the procedure and/or the instrument in question.

a. If the answer to question 4 was affirmative, how can the acceptance test be made easier?

b. Would providing training in performing the procedures and using the instrumentation help?

c. Does your office currently possess any TAB instrumentation? If so, identify them, and describe the purpose(s) they are used for.

6. How useful or informative was the data provided by the test?

7. Besides the four components tested in this procedure, what other components of the HVAC system should be tested?

8. Should acceptance testing be the responsibility of the FOA or the District?

9. Space for additional comments.

APPENDIX E: VERBATIM PARTICIPANT COMMENTS ON THE T^3B TEST

Participants:

FD = Fort Drum
FH = Fort Huachuca (AO = Area Office, RO = Resident Office)
FJ = Fort Jackson
FM = Fort McClellan
VA = Vance AFB

3. Did any problems that could impact acceptance testing occur during installation of the air supply and distribution system? If so, describe in detail.

FD--No.

FH--No.

FJ--Not to my knowledge. However, during the brief discussion preceding our demonstration, we were told it would be best to have a copy of the TAB report in hand.

FM--Two of the return grills were not installed as shown on the drawings. They were installed adjacent to the auditorium seating which made it impossible to measure return air flows.

FM--The space allocated for the HVAC equipment was not large enough, thus causing the equipment and duct to be crowded into the space which make finding good test and balance points difficult.

VA--None, to my knowledge.

4. During installation and TAB of the air supply and distribution system, which Corps FOA personnel is responsible for maintaining QA and reviewing the TAB reports respectively?

FD--[Fort Drum's Corps] QA branch and mechanical engineers.

FH--[Phoenix] Area Office mechanical engineer is responsible for QA and TAB report review. (Technically Resident Engineer is responsible but he defers to Area QA in practice.) [AO]

FH--Both the Construction Representative at the Resident Office and the Mechanical Engineer from the Area Office. [RO]

FJ--Not sure; each base is different.

FM--The Corps FOA personnel responsible for maintaining Quality Assurance and reviewing the TAB are the project Engineer for this particular job and a mechanical engineer specialist from the Area Office.

VA--The Project Office quality assurance representative maintains the daily QA reports and QC oversite [sic]. The TAB reports were reviewed by an engineer at the Area Office.

5. Were the acceptance test procedures or the measuring instrumentation too difficult or time consuming to use? Explain why and identify the procedure and/or the instrument in question.

FD--No.

FH--No.

FJ--No, though it will take more than 1 person several hours to do the testing.

FM--All of the equipment was relatively easy to use. The only piece of equipment that was time consuming to use was the differential pressure gauge. The reason it was time consuming was because we lacked the proper fittings to hook it up to the piping. In time, we will acquire the necessary fittings to fit most of the systems we run across.

VA--No. As a spot check, the time consumed was quite acceptable.

5a. If the answer to question 4 was affirmative, how can the acceptance test be made easier?
(There were no responses to this question.)

5b. Would providing training in performing the procedures and using the instrumentation help?

FD--Yes, using anemometer, hood and set-up of gpm. Plus observation of pump installation was helpful.

FH--Yes. [AO]

FH--Yes, familiarization with any testing equipment is good. [RO]

FJ--Yes, and 1 or 2 people per field office should do all the testing.

FM--Training will be required for personnel that have never used this type of equipment.

VA--Yes--for those who have access to instruments but do not know how to use [them].

5c. Does your office currently possess any TAB instrumentation? If so, identify them, and describe the purpose(s) they are used for.

FD--No.

FH--Our Area Office has only minor test equipment: 1. Thermometers - measuring air temperatures; 2. "Ben Casey" - Squeeze pneumatic bulb to validate pneumatic system pressures. [AO]

FH--No. [RO]

VA--Design branch has a flowhood, B&G circuit setter, pitot flow meter. Used mostly for trouble-shooting and investigation and correction of latent defects.

6. How useful or informative was the data provided by the test?

FD--Very useful, especially interpretation of low static pressure results.

FH--The data provided was useful and informative. It caused us to question the Contractor's baffled flow hood readings. [AO]

FH--Very useful especially to confirm the TAB from the contractor. [RO]

FJ--Very, checking behind the Contractor is a necessary task if we are to ever get what we design.

FM--The information provided by the acceptance test was very valuable. Based on the acceptance test that we performed we intend to reject the previously approved TAB report.

VA--Demonstrated the value of the procedure--especially the forms. As a good follow-up to verify compliance with plans and specs and to prevent user complaints.

7. Besides the four components tested in this procedure, what other components of the HVAC system should be tested?

FD--Coil chilled water flows.

FH--The control systems should be validated. [AO]

FH--None. [RO]

FJ--Efficiencies of all motors.

FM--Other components that should be tested are VAV systems, hydronics, chillers, boilers, and exhaust systems.

VA--VAV boxes.

8. Should acceptance testing be the responsibility of the FOA or the District?

FD--FOA.

FH--Acceptance testing should be the responsibility of the Area or District Office as qualified TAB personnel are normally not found at Resident and Project Offices. [AO]

FH--FOA. [RO]

FJ--I think both. At times, Field Offices do not have the time/personnel to complete the task and the District should be able to step in.

FM--It is our opinion that acceptance testing should be used as a quality assurance tool and should be the responsibility of the District unless the work load is so great that qualified individuals would routinely be available in Area Offices to perform this function.

VA--The District. Possibly the Area Office staff, if adequate equipment and training is provided. If not, the District.

9. Space for additional comments.

FD--Request a catalog list of light, compact measuring devices for air flow, gpm flow, electrical measurement amps & volts and shaft speeds. Measuring devices should include all attachments and accessories, tools, drills, bits, tape, etc. to use devices.

FD--Although it may be impossible to get the Contractor to make changes at the end of warranty period, with the correct equipment, we may be able to improve the situation.

FH--Hands on training and utilization of testing equipment and explanation by CERL was very useful to our personnel at the Resident Office.

FM--We thoroughly enjoyed the opportunity to help you trouble shoot the acceptance test. We will notify you of the upcoming buildings we intend to check so you can make arrangements to be there if time and money permit. Here is a list of the things we thought needed changing.

1. Consider adding design flow (cfm) and design velocity (fpm) on the bottom of the duct traverse data sheet. Refer to the package submitted by [us].

2. It is our opinion that T_z on the duct system data sheet is not of much value to the Quality Assurance program. Consider removing the columns. This would alter [the duct calculations sheet] as well.

3. Add an "as submitted" column to [the fan system data sheet] and other [data sheets] as required.

4. On [the duct data sheet] what do you mean by "proper position"? Are you speaking of automatic dampers or fixed dampers or both? If discussing fixed dampers we would not know if the damper was in the proper location until we were finished with the test. This needs a bit of clarification.

5. On [the duct calculations data sheet] what do you mean by volumetric airflow at zone inlet? Are you trying to compare air flow at a traversed portion of duct to the air that comes out of the diffusers downstream or are you comparing supply to return? This needs a bit of clarification.

VA--These testing procedures could become very useful in addressing the TAB verification problem, IF adequate levels of training and testing equipment is provided.

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